51	International Patent Category 6 H01L 21/027, G03F 7/20		
11	International Laid Open Number	WO99/49504	
43	International Laid Open Date	9/30/1999	
21	International Application Number	PCT/JP99/01262	
22	International Date of Application	3/16/1999	
30	Priority Right Data	JP H10/79263	3/26/1998
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54 PROJECTION EXOSURE METHOD AND SYSTEM

57 Abstract

It is a projection exposure method capable of keeping a liquid 7 filled between a projection optical system PL and a wafer W even while wafer W is being moved when a liquid immersion method is used to perform an exposure. A discharge nozzle 21a and inflow nozzles 23a and 23b are disposed in the manner that a lens 4 at the end of projection optical system PL is held between them in the X direction. When wafer W is moved in the negative X-direction by an XY stage 10, liquid 7 controlled to a predetermined temperature is supplied from a liquid supply device 5 via a supply pipe 21 as well as discharge nozzle 21a so as to fill the space between lens 4 and the surface of wafer W, and liquid 7 is recovered from the surface of wafer W by a liquid supply device 6 via a recovery pipe 23 as well as inflow nozzles 23a and 23b. The supply volume and recovery volume of liquid 7 is regulated according to a moving speed of wafer W.

Specification

Projection Exposure Method and Apparatus

Field of Technology

The present invention relates to a projection exposure method and apparatus used for transferring a mask pattern onto a photosensitive substrate in the lithography process for manufacturing devices such as a semiconductor device, imaging device such as CCD, liquid crystal display device or a thin film magnetic head, and more specifically relates to a projection exposure method and apparatus using a liquid immersion method.

Background Technology

When manufacturing a semiconductor device, etc., a projection exposure apparatus, wherein a pattern on a reticle as a mask is transferred onto each shot area on a wafer (or a glass plate, etc.) as a photosensitive substrate coated with a resist, is used. Conventionally, a step-and-repeat method reduction projection type exposure apparatus (stepper) has been in heavy usage as a projection exposure apparatus, but recently, a step-and-scan method projection exposure apparatus that performs an exposure by synchronously scanning a reticle and a wafer has been attracting attention as well.

The shorter the operating exposure wavelength is, and the greater the numerical aperture of a projection optical system is, the higher the resolution of the projection optical system equipped in a projection exposure apparatus becomes. Therefore, the exposure wavelength used in a projection exposure apparatus is getting shorter every year to accompany the miniaturization of an integrated circuit, and the numerical aperture of a projection optical system is also increasing. And although the current mainstream exposure wavelength is 248nm of KrF excimer laser, a further shorter wavelength of 193nm of ArF excimer laser is also about to be put to practical use.

Furthermore, when performing an exposure, a depth of focus (DOF) becomes as important as a resolution. A resolution R and a depth of focus δ can be expressed with the following equations, respectively.

$$R=k_1 \cdot \lambda/NA \qquad 1$$

$$\delta=k_2 \cdot \lambda/NA^2 \qquad 2$$

Here, λ is an exposure wavelength, NA is a numerical aperture of a projection optical system, k_1 and k_2 are process coefficients. From Equation 1 and Equation 2, it is evident that depth of focus δ becomes narrower if exposure wavelength λ is shortened and numerical aperture NA is increased in order to increase resolution R. Conventionally, in a projection exposure apparatus, an auto focus method is used to align a wafer surface to an image plane of a projection optical system to perform an exposure, and for that, it would be preferable if depth of focus δ is wide to some extent. Therefore, proposals to essentially widen the depth of focus, such as the phase shit reticle method, deformable resolution enhancement technique, multi-layer resist method, etc, have been made in the past.

As described above, in a conventional projection exposure apparatus, the depth of focus has been narrowed by the shortening of the exposure light wavelength and the increase in the numerical aperture of the projection optical system. And in order to accommodate further integration of a semiconductor integrated circuit, researches are being conducted to further shorten the exposure wavelength, and with the way things are going, the depth of focus could become so narrow that the margin for an exposure motion may no longer be sufficient.

Therefore, a liquid immersion method has been proposed as a method to essentially shorten the exposure wavelength as well as widen the depth of focus. The idea is to fill the space between the bottom surface of a projection optical system and the wafer surface with either water or an organic solvent, etc., and by taking advantage of the fact that the

exposure beam wavelength in a liquid becomes 1/n (n is a refractive index of a liquid, which is normally somewhere between 1.2 to 1.6) of that in air, the depth of focus is increased by about a factor of n while improving the resolution.

If this liquid immersion method is merely applied to a step-and-repeat type projection exposure apparatus, it would be inconvenient because, after an exposure of one shot area is finished, when moving a wafer in steps to the next shot area, a liquid will come out from between the projection optical system and the wafer, so the liquid needs to be supplied again, and the recovery of the liquid would also be difficult. Also, if the liquid immersion method is applied to the step-and-scan type projection exposure apparatus, since an exposure is performed while moving a wafer, it is necessary to keep the space between the projection optical system and the wafer filled even while the wafer is being moved.

In light of these points, the purpose of the present invention is to provide a projection exposure apparatus capable of stably keeping the space between a projection optical system and a wafer filled even when the projection optical system and the wafer are relatively moving when the liquid immersion method is applied. Furthermore, another purpose of the present invention is to provide a projection exposure apparatus capable of implementing such projection exposure method, an efficient manufacturing method of such projection exposure apparatus and a method for manufacturing a highly functional device using such projection exposure method.

Disclosure of the Invention

The first projection exposure method according to the present invention is such that, in the projection exposure method wherein a mask R is irradiated with an exposure beam, and a pattern on mask R is transferred onto a substrate W through a projection optical system PL, when substrate W is being moved along a predetermined direction, a predetermined liquid 7 is passed along the direction of the motion of substrate W so as to

fill the space between the end of optical element 4 on the substrate W side of projection optical system PL and the surface of substrate W.

According to such first projection exposure method of the present invention, because a liquid immersion method is applied and the space between the end of projection optical system PL and substrate W is filled with the liquid, the wavelength of the exposure beam on the substrate surface can be shortened to 1/n (n is a refractive index of the liquid) of that in air, and also, the depth of focus will be increased by about a factor of n relative to the one in air. Also, when moving the substrate along the predetermined direction, because the liquid is passed along the direction of the motion of the substrate, even when the substrate is being moved, the space between the end of the projection optical system and the surface of the substrate is filled with the liquid. Also, if any particles have adhered to the substrate, such particles that have adhered on the substrate can be flushed out with the liquid.

Next, the first projection exposure apparatus according to the present invention is such that, in the projection exposure apparatus wherein mask R is irradiated with an exposure beam and a pattern on mask R is transferred onto substrate W through projection optical system PL, it has substrate stages 9 and 10 for holding and moving substrate W, a liquid supply device 5 for supplying predetermined liquid 7 along a predetermined direction through a supply pipe 21a so as to fill the space between the end of optical element 4 on the substrate W side of projection optical system PL and the surface of substrate W, and a liquid recovery device 6 for recovering liquid 7 from the surface of substrate W through discharge pipes 23a and 23b disposed in the manner that the exposure beam's irradiation range is put between it and supply pipe 21a along the predetermined direction; and when driving substrate stages 9 and 10 to move substrate W along the predetermined direction, it supplies and recovers liquid 7.

According to the first projection exposure apparatus of the present invention, by using these pipe arrangements, the first projection exposure method of the present invention can be implemented.

Also, it is preferable to provide a second pair of pipes for supply 22a and for discharge 24a and 24b at the location where the first pair of pipes for supply 21a and for discharge 23a and 23b would be if it were essentially rotated by 180°. In such a case, when moving substrate W in the direction opposite of a predetermined direction, by using the latter pair of pipes, the space between the end of projection optical system PL and the surface of substrate W can be stably filled with liquid 7.

Also, if the projection exposure apparatus is a scanning exposure type wherein mask R and substrate W are synchronously moved relative to projection optical system PL to perform an exposure, it is preferable if the predetermined direction is the scanning direction of substrate W during a scanning exposure. In such a case, even during a scanning exposure, the space between the end of optical element 4 on the substrate W side of projection optical system PL and the surface of substrate W can be continuously filled with liquid 7, and a high precision and stable exposure can be performed.

Also, it is preferable to provide a pair or two pairs of pipes for supply 27a and for discharge 29a and 29b in the manner corresponding to the pair of pipes for supply 21a and for discharge 23a and 23b in the direction orthogonal to the predetermined direction. In such a case, even when substrate W is moved in steps in the direction orthogonal to the predetermined direction, the space between the end of projection optical system PL and the surface of substrate W can be continuously filled with liquid 7.

Also, it is preferable to have a control system 14 for regulating the supply volume as well as recovery volume of liquid 7 in accordance with the velocity of the motion of the substrate stage. In other words, for instance, if the velocity of the motion is fast, by

increasing the supply volume, and if the velocity of the motion is slow, by decreasing the supply volume, the liquid can be maintained constant in the space between the end of projection optical system PL and the surface of substrate W.

Furthermore, liquid 7 supplied to the surface of substrate W is, as one example, purified water controlled to be at a predetermined temperature or a fluorinated inert liquid. In such a case, purified water, for example, can be easily obtained at semiconductor manufacturing plants and does not cause any environmental problem. Also, because liquid 7 is temperature-controlled, the temperature of the substrate surface can be controlled, and thereby thermal expansion of substrate W caused by heat generated during an exposure can be prevented. It is naturally preferable if the transmittance of the liquid relative to an exposure beam is high, but even when the transmittance is low, because the working distance of the projection optical system is short, the amount of the exposure beam absorbed is extremely small.

Next, the manufacturing method of the projection exposure apparatus according to the present invention is for manufacturing a projection exposure apparatus by assembling, in a predetermined positional relationship, an illumination unit 1 for irradiating an exposure beam on mask R, projection optical system PL for transferring the pattern of the mask onto substrate W, substrate stage 9 and 10 for holding and moving substrate W, liquid supply device 5 for supplying predetermined liquid 7 along a predetermined direction through pipe for supply 21a so as to fill the space between the end of optical element 4 on the substrate W side of projection optical system PL and the surface of substrate W, liquid recovery device 6 for recovering liquid 7 from the surface of substrate W through pipes for exhaust 23a and 23b disposed in the manner that irradiation area 4 of the exposure beam is put between it and supply pipe 21a in a predetermined direction.

Also, the first device manufacturing method according to the present invention is a device manufacturing method using the first projection exposure method of the present

invention, which includes an exposure process wherein mask R is irradiated with an exposure beam, and the pattern on mask R is transferred onto substrate W for a device through projection optical system R; and in this exposure process, when moving substrate W along a predetermined direction, predetermined liquid 7 is passed along the direction of the motion of substrate W so as to fill the space between the end of optical element 4 on the substrate W side of projection optical system PL and the surface of substrate W, and the application of the liquid immersion method enables a manufacturing of highly functional devices.

Next, the second projection exposure method of the present invention is such that, in a projection exposure method wherein mask R is irradiated with an exposure beam and substrate W is exposed with the exposure beam through projection optical system PL, liquid 7 is passed so as to fill the space between the projection optical system and the substrate, and the direction in which the liquid is passed is also changed in accordance with the direction of the motion of the substrate.

According to the second projection exposure method of the present invention, a liquid immersion method is applied and the space between projection optical system PL and substrate W is filled with the liquid, so the wavelength of the exposure light at the surface of the substrate can be shortened to 1/n (n is a refractive index of the liquid) of the wavelength in air, and furthermore, the depth of focus can be widened by about a factor of n compared to that in air. Also, by varying the direction of the flow of the liquid in accordance with the direction of the motion of the substrate, even when the direction of the motion of the substrate changes frequently, the liquid can be filled in the space between the projection optical system and the substrate.

Also, when the supply speed of liquid 7 is divided into the first component in the direction of the motion of the substrate and the second component in the direction orthogonal to the direction of the motion, if the first component is in the opposite direction

of the moving direction of substrate W, it is preferable if liquid 7 is passed in the manner that the first component is smaller than a predetermined tolerable value. This will reduce the velocity component of the liquid in the direction opposite of the direction of the motion of substrate W, and thereby smooth the supply of the liquid.

Also, it is preferable to pass liquid 7 in the direction essentially along the direction of the motion of substrate W.

Also, when substrate W is exposed either by a step-and-repeat method or step-and-scan method, it is preferable if liquid 7 is passed in the direction almost along the stepping direction of substrate W.

Also, it is preferable if mask R and substrate W move relative to the exposure beam respectively, and in addition to scanning and exposing the substrate with the exposure beam, during the scanning exposure, liquid 7 is passed almost along the scanning direction of the substrate.

Also, it is preferable to regulate the flow rate of liquid 7 in accordance with the velocity of the motion of substrate W.

Next, the second device manufacturing method according to the present invention includes a lithography process having a process for transferring a device pattern onto substrate W using the second projection exposure method of the present invention, and a liquid immersion method is applied so that highly functional devices can be manufactured.

Next, the second projection exposure apparatus according to the present invention is such that, in a projection exposure apparatus for illuminating mask R with an exposure beam and exposing substrate W with the exposure beam through projection optical system PL, in addition to passing liquid 7 so as to fill the space between the projection optical

system and substrate, it is equipped with liquid supply device 5 for changing the direction the liquid is passed in accordance with the direction of the motion of the substrate.

With such second projection exposure apparatus of the present invention, the second projection exposure method of the present invention can be implemented, and even in the case where the direction of the motion of the substrate changes frequently, the liquid can be filled between the projection optical system and the substrate.

Also, it is preferable if it is further equipped with a stage system (RST, 9 ~ 11) for moving mask R and substrate W relative to the exposure beam respectively, and liquid supply device 5 passes liquid 7 almost along the direction of the motion of the substrate during a scanning exposure of the substrate.

Also, it is desirable if it is further equipped with liquid recovery device 6 for recovering liquid 7 supplied between projection optical system PL and substrate W.

Also, it is desirable to dispose supply port 21a of liquid supply device 5 and recovery ports 23a and 23b of liquid recovery device 6 in the manner that they put the irradiation range of the exposure beam between them.

Brief Explanation of Figures

Figure 1 is the schematic structure of the projection exposure apparatus used in the first embodiment of the present invention. Figure 2 is a Figure showing the positional relationship of an end 4A of lens 4 of projection optical system PL and the discharge nozzle as well as inflow nozzle for the X direction. Figure 3 is a Figure showing the positional relationship of end 4A of lens 4 of projection optical system PL in Figure 1 and the discharge nozzle and the inflow nozzle for supplying and recovering the liquid from the Y direction. Figure 4 is an enlarged view of the key part showing the way liquid 7 is supplied

to and recovered from the space between lens 4 in and wafer W in Figure 1. Figure 5 is a front view showing the bottom end of projection optical system PLA of the projection exposure apparatus used in the second embodiment of the present invention, liquid supply device 5 and liquid recovery device 6, etc. Figure 6 is a Figure showing the positional relationship of an end 32A of a lens 32 of projection optical system PLA in Figure 5 and the discharge nozzle as well as the inflow nozzle for the X direction. Figure 7 is a Figure showing the positional relationship of the discharge nozzle as well as the inflow nozzle for supplying and recovering the liquid from the Y direction.

Preferred Embodiments of the Invention

Following, we will explain an example of a preferred embodiment of the present invention while referring to Figures 1 through 4. This example shows when the present invention is applied when performing exposure using a step and repeat method projection exposure apparatus.

Figure 1 shows the schematic structure of the projection exposure apparatus of this example, and in Figure 1, exposure light IL consisting of wavelength 248 nm ultraviolet pulse light projected from illumination optics 1 which comprises a KrF excimer laser light source as an exposure light source, an optical integrator (homogenizer), a field stop, and a condenser lens, irradiates a pattern provided on reticle R. The pattern of reticle R undergoes reduction projection on the exposure area on wafer W which is coated with photoresist using a predetermined projection magnification β (β can be 1/4 or 1/5, for example) via a both sided (or one side on the wafer W side) telecentric projection optical system PL. As exposure light IL, it is also possible to use ArF excimer laser light (wavelength 193 nm), F_2 laser light (wavelength 157 nm), or i-line beam of a mercury lamp (wavelength 365 nm). Following, we will explain the Z-axis in parallel with the projection optical system PL

optical axis AX, the Y-axis perpendicular to the paper surface of Figure 1 within the plane perpendicular to the Z-axis, and the X-axis in parallel to the paper surface of Figure 1.

Reticle R is held over reticle stage RST, and a mechanism is incorporated in reticle stage RST that does fine movement of reticle R in the X direction, Y direction, and rotation direction. The two dimensional position of reticle stage RST and the rotation angle are measured in real time using a laser interferometer (not illustrated), and main control system 14 determines the position of reticle R based on these measurement values.

Meanwhile, wafer W is fixed above Z stage 9 that controls the focus position (position in the Z direction) and tilt angle of wafer W via a wafer holder (not illustrated). Z stage 9 is fixed above XY stage 10 that moves along the XY plane that is essentially parallel to the image plane of the projection optical system PL, and XY stage 10 is placed over base 11. Z stage 9 controls the wafer W focus position (position in Z direction) and tilt angle to align the surface above wafer W with the image plane of the projection optical system PL using the auto focus method and the auto leveling method, and XY stage 10 determines the position of wafer W in the X direction and the Y direction. The two-dimensional position and rotation angle of Z stage 9 (wafer W) are measured in real time by a laser interferometer 13. Control information is sent from main control system 14 to wafer stage drive system 15 based on these measurement results, and based on this, wafer stage drive system 15 controls the operation of Z stage 9 and XY stage 10. At the time of exposure, each shot area on wafer W is moved in steps in sequence on the exposure position, and the operation of exposing the pattern image of reticle R is repeated by the step-and-repeat method.

With this example, while the exposure wavelength is essentially shortened and the resolution improved, to essentially broaden the depth of focus, a liquid immersion method is used. To do this, at least during the time that the pattern image of reticle R is being transferred onto wafer W, a predetermined liquid 7 is filled between the surface of wafer W

and the end (the bottom surface) of lens 4 on the wafer side of the projection optical system PL. Projection optical system PL has a lens barrel 3 that holds other optical systems and a lens 4, and is constructed so that liquid 7 contacts only lens 4. By doing this, corrosion, etc. of the lens barrel 3 that is made of metal is prevented.

Moreover, projection optical system PL consists of multiple optical elements including lens 4, and lens 4 is fixed so as to be attached and removed (replaced) freely at the very bottom of the lens barrel 3. With this example, the optical element that is closest to wafer W, in other words, that contacts liquid 7, is a lens, but this optical element is not limited to being a lens, and it is also acceptable for it to be an optical plate (plane-parallel plate, etc.) used for adjusting optical characteristics of the projection optical system PL such as aberration (spherical aberration, coma aberration, etc.). Also, due to scattered particles that occur from resist due to irradiation of exposure light or of adhesion of impurities in liquid 7, etc., the surface of the optical element that contacts liquid 7 becomes contaminated, so it is necessary to periodically replace that optical element. However, when the optical element that contacts liquid 7 is a lens, the cost of this replacement part is high, and a long time is required to replace it, and this invites a rise in maintenance costs (running cost) and a decrease in throughput. In light of this, it is also acceptable to have the optical element that contacts liquid 7 be a plane-parallel plate that is less expensive than a lens 4, for example. In this case, at times such as the transport, assembly, and adjustment of the projection exposure apparatus, even if a substance (such as a silicon organic substance) that decreases things like the transmittance of the projection optical system PL, the light intensity of the exposure light on wafer W, or the uniformity of the light intensity distribution adheres to the plane-parallel plate, all that needs to be done is to replace the plane-parallel plate immediately before liquid 7 is supplied, so there is also the advantage that the replacement cost is lower compared to when the optical element that contacts liquid 7 is a lens.

Also, with this example, purified water, for example, can be used as liquid 7. Purified water can be easily obtained in large volumes at a semiconductor manufacturing factory, etc., and it also has the advantage of not having an adverse effect on the photoresist on the wafer or optical lens, etc. Also, purified water not only has no adverse effect on the environment but also contains very little amount impurities, so the effect of its washing the wafer surface and the surface of lens 4 can also be anticipated.

Then, because the refractive index of purified water (water) relative to exposure light of a wavelength of approximately 250 nm is approximately 1.4, the KrF excimer laser light wavelength 248 nm is shortened by 1/n, in other words, shortened to approximately 177 nm, so high resolution can be obtained. Furthermore, compared to in air, the depth of focus is widened by approximately a factor of n, in other words, approximately by 1.4, so in cases when it would be good as long as the depth of focus equivalent of the one in air can be ensured, it is possible to further increase the numerical aperture of projection optical system PL, and this also improves resolution.

This liquid 7 is supplied in a temperature controlled state onto wafer W via a predetermined discharge nozzle, etc. by liquid supply device 5 consisting of a tank for the liquid, a pressurization pump, and a temperature control device, etc., and using a liquid recovery device 6 consisting of the liquid tank and a suction pump, etc., the liquid is recovered from on wafer W via a predetermined inflow nozzle, etc. The temperature of liquid 7 is set at about the level of the temperature within the chamber in which the projection exposure apparatus of this example is housed, for example. And, a fine-end tip discharge nozzle 21a and two expanded-end inflow nozzles 23a and 23b (see Figure 2) are arranged so as to sandwich the end of lens 4 of projection optical system PL in the X direction, and discharge nozzle 21a is connected to liquid supply device 5 via supply pipe 21 while inflow nozzles 23a and 23b are connected to liquid recovery device 6 via recovery pipe 23. Furthermore, there are also two pairs of discharge nozzles and inflow nozzles arranged so as to sandwich in the Y direction the end of lens 4 and a pair of nozzles placed

at the location where the pair of discharge nozzles 21a and inflow nozzles 23a and 32b would be if it were rotated by about 180 °.

Figure 2 shows the positional relationship of the end 4A of lens 4 of projection optical system PL and wafer W of Figure 1, and the two pairs of discharge nozzles and inflow nozzle that sandwich this end 4A in the X direction, and in this Figure 2, discharge nozzle 21a is arranged on the +X direction side of end 4A while inflow nozzles 23a and 23b are arranged on the –X direction side. Also, inflow nozzles 23a and 23b are arranged in a form that opens like a fan in relation to the axis that is parallel to the X axis through the center of end 4A. Then, at the location where the pair of discharge nozzles 21a and inflow nozzles 23a and 23b would be if it were rotated by about 180 °, a separate pair of discharge nozzles 22a and inflow nozzles 24a and 24b are arranged with discharge nozzle 22a connected to liquid supply device 5 via supply pipe 22 and inflow nozzles 24a and 24b connected to liquid recovery device 6 via recovery pipe 24.

Also, Figure 3 shows the positional relationship of end 4A of lens 4 of projection optical system PL of Figure 1 and the two pairs of discharge nozzles and inflow nozzles that sandwich this end 4A in the Y direction, and in this Figure 3, discharge nozzle 27a is arranged in the +Y direction side of end 4A, while inflow nozzles 29a and 29b are arranged in the –Y direction side, with discharge nozzle 27a connected to liquid supply device 5 via supply pipe 27 and inflow nozzles 29a and 29b connected to liquid recovery device 6 via recovery pipe 29. Also, a separate pair discharge nozzle 28a and inflow nozzles 29a and 29b are arranged at the location where pair of discharge nozzles 27a and inflow nozzles 29a and 29b would be if it were rotated by about 180°, and discharge nozzle 28a is connected to liquid supply device 5 via supply pipe 28 and inflow nozzles 30a and 30b are connected to liquid recovery device 6 via recovery pipe 30. Liquid supply device 5 supplies temperature-controlled liquid between end 4A of lens 4 and wafer W via at least one of supply pipes 21, 22, 27 and 28, and liquid recovery device 6 recovers that liquid via at least one of recovery pipes 23, 24, 29 and 30.

Next, we will explain the methods for supplying and recovering liquid 7.

In Figure 2, when moving wafer W in steps in the direction of arrow 25A (–X direction) shown by the solid line, liquid supply device 5 supplies liquid 7 between end 4A of lens 4 and wafer W via supply pipe 21 and discharge nozzle 21a. Then, liquid recovery device 6 recovers liquid 7 from on wafer W via recovery pipe 23 and inflow nozzles 23a and 23b. At this time, liquid 7 flows in the direction of arrow 25B (–X direction) on wafer W, and there is stable filling of liquid 7 in between wafer W and lens 4.

Meanwhile, when moving wafer W in steps in the direction of arrow 26A (+X direction) shown by the dot-dash line, liquid supply device 5 supplies liquid 7 between end 4A of lens 4 and wafer W using supply pipe 22 and discharge nozzle 22a, and liquid recovery device 6 recovers liquid 7 using recovery pipe 24 and inflow nozzles 24a and 24b. At this time, liquid 7 flows on wafer W in the direction of arrow 26B (+X direction), and the space between wafer W and lens 4 is filled with liquid 7. In this way, with the projection exposure apparatus of this example, because two pairs of discharge nozzles and inflow nozzles that are reverse to each other in the X direction are provided, even when wafer W moves in either the +X direction or the –X direction, it is possible to continue filling the space between wafer W and lens 4 stably with liquid 7.

Also, because liquid 7 flows over wafer W, even in cases when particles (including scattered particles from the resist) adhere on wafer W, there is the advantage that it is possible to remove the particles by the flow of liquid 7. Also, because liquid 7 is adjusted to a predetermined temperature by liquid supply device 5, temperature of the wafer W surface is adjusted, and this prevents a degradation of overlay accuracy, etc. due to thermal expansion of the wafer due to heat that is generated during exposure. Therefore, even when there is a time difference with alignment and exposure as with alignment using the EGA (enhanced global alignment) method, it is possible to prevent a degradation of overlay accuracy due to thermal expansion of the wafer. Also, with the projection exposure

apparatus of this example, liquid 7 flows in the same direction as the direction that wafer W is moved, so it is possible to recover liquid that has absorbed particles and heat without it pooling on the exposure area directly under end 4A of lens 4.

Also, when moving wafer W in steps in the Y direction, supply and recovery of liquid 7 is done from the Y direction.

Specifically, when moving wafer W in steps in the direction of arrow 31A (–Y direction) shown by the solid line in Figure 3, liquid supply device 5 supplies liquid via supply pipe 27 and discharge nozzle 27a, and liquid recovery device 6 recovers liquid using recovery pipe 29 and inflow nozzles 29a and 29b, and the liquid flows in the direction of arrow 31B (–Y direction) over the exposure area directly under end 4A of lens 4. Also, when moving the wafer in steps in the +Y direction, liquid is supplied and recovered using supply pipe 28, discharge nozzle 28a, recovery pipe 30, and inflow nozzles 30a and 30b, and the liquid flows in the +Y direction over the exposure area directly under end 4A. By doing this, as when wafer W is moving in the X direction, even when wafer W is moving in either the +Y direction or the –Y direction, it is possible to fill the space between wafer W and end 4A of lens 4 with liquid 7.

Moreover, rather than only using nozzles that perform supply and recovery of liquid 7 from the X direction or Y direction, it is also acceptable to provide a nozzle for performing supply and recovery of liquid 7 from a diagonal direction, for example.

Next, we will explain the method of controlling the supply volume and recovery volume of liquid 7.

Figure 4 shows the situation of supply and recovery of liquid 7 to the space between lens 4 of projection optical system PL and wafer W, and in this Figure 4, wafer W moves in the direction of arrow 25A (–X direction), and liquid 7 supplied from discharge nozzle 21a

flows in the direction of arrow 25B (–X direction), with recovery done by inflow nozzles 23a and 23b. In order to keep the volume of liquid 7 that exists between lens 4 and wafer W constant even while wafer W is moving, in this example, the liquid 7 supply volume Vi (m^3/s) and recovery volume Vo (m^3/s) are kept equal, and the liquid 7 supply volume Vi and recovery volume Vo are adjusted to be proportional to the moving speed v of XY stage 10 (wafer W). Specifically, main control system 14 determines supply volume Vi and recovery volume Vo of liquid 7 using the formula below.

$$Vi = Vo = D \cdot v \cdot d \quad (3)$$

Here, as shown in Figure 1, D is the diameter (m) of the end of lens 4, v is the velocity of the motion (m/s) of XY stage 10, and d is the working distance (m) of projection optical system PL. The velocity v when moving XY stage 10 in steps is set by main control system 14, and because D and d are input in advance, by adjusting the supply volume Vi and recovery volume Vo of liquid 7 using formula (3), the space between lens 4 of Figure 4 and wafer W is always filled with liquid 7.

Moreover, it is preferable to make working distance d of projection optical system PL as narrow as possible to have stable existence of liquid 7 between projection optical system PL and wafer W. However, if working distance d is too small, there is the risk of the surface of wafer W contacting lens 4, so it is necessary to keep a certain level of margin. In light of this, working distance d is set at about 2 mm as an example. Working distance d is short as shown here, so even if the transmittance of liquid 7 relative to the exposure light is low to some extent, the amount of the exposure light absorbed is very small.

Next, we will explain a second embodiment of the present invention while referring to Figures 5 through 7. This example applies the present invention when exposure is done using a step-and-scan method projection exposure apparatus.

Figure 5 is a front view that shows the bottom of the projection optical system PLA, liquid supply device 5, and liquid recovery device 6, etc. of the projection exposure apparatus of this example, and in Figure 5 that shows the same code numbers for parts that correspond to this Figure 4, lens 32 at the bottom end of lens barrel 3A of projection optical system PLA is ground to a long, thin rectangle in the Y direction (non scanning direction) leaving end 32A only for the amount necessary for scanning exposure. During scanning exposure, the pattern image of part of the reticle is projected on the rectangular exposure area directly under end 32A, and in synchronization with the motion at velocity V of the reticle (not illustrated) in the –X direction (or the +X direction) relative to projection optical system PLA, wafer W moves at speed $\beta \cdot V$ (β is the projection magnification) in the +X direction (or –X direction) via XY stage 10. Then, after exposure on one shot area ends, with the stepping of wafer W, the next shot area moves to the scan start position, and thereafter exposure is done in sequence to each shot area using the step-and-scan method.

With this example as well, through use of the liquid immersion method during scanning exposure, the space between lens 32 and the surface of wafer W is filled with liquid 7. Supply and recovery of liquid 7 is performed respectively by liquid supply device 5 and liquid recovery device 6.

Figure 6 shows the positional relationship of end 32A of lens 32 of projection optical system PLA and the discharge and inflow nozzles for supplying and recovering liquid 7 in the X direction, and in Figure 6, the shape of end 32A of lens 32 is long, thin and rectangular in the Y direction, and three discharge nozzles 21a to 21c are arranged on the +X direction side and two inflow nozzles 23a and 23b are arranged on the –X direction side so that they sandwich end 32A of lens 32 of projection optical system PLA in the X direction.

Also, discharge nozzles 21a to 21c are connected to liquid supply device 5 via supply pipe 21, and inflow nozzles 23a and 23b are connected to liquid recovery device 6

via recovery pipe 23. Discharge nozzles 22a to 22c and inflow nozzles 24a and 24b are arranged a the locations where discharge nozzles 21a to 21c and inflow nozzles 23a and 23b would be if they were rotated by about 180 °. Discharge nozzles 21a to 21c and inflow nozzles 24a and 24b are aligned alternately in the Y direction, discharge nozzles 22a to 22c and inflow nozzles 23a and 23b are aligned alternately in the Y direction, and discharge nozzles 22a to 22c are connected to liquid supply device 5 via supply pipe 22 while inflow nozzles 24a and 24b are connected to liquid recovery device 6 via recovery pipe 24.

Then, when performing scanning exposure by moving wafer W in the scan direction shown by the solid line arrow (–X direction), supply and recovery of liquid 7 is performed by liquid supply device 5 and liquid recovery device 6 using supply pipe 21, discharge nozzles 21a to 21c, recovery pipe 23, and inflow nozzles 23a and 23b and liquid 7 is passed in the –X direction so as to fill in between lens 32 and wafer W. Also, when performing scanning exposure by moving wafer W in the direction shown by the dot-dash arrow (+X direction), supply and recovery of liquid 7 is performed using supply pipe 22, discharge nozzles 22a to 22c, recovery pipe 24, and inflow nozzles 24a and 24b, and liquid 7 is passed in the +X direction so as to fill in between lens 32 and wafer W. By switching the direction liquid 7 flows according to the scan direction, when scanning wafer W in either the +X direction or the –X direction, it is possible to fill the space between end 32A of lens 32 and wafer W with liquid 7, and to obtain high resolution and wide depth of focus.

Also, the supply volume Vi (m^3/s) and recovery volume Vo (m^3/s) of liquid 7 are determined using the formula below.

$$Vi = Vo = D_{SY} \cdot v \cdot d \quad (4)$$

Here, D_{SY} is the length (m) of end 32A of lens 32 in the X direction. By doing this, it is possible to stably fill the space between lens 32 and wafer W with liquid 7 even during scanning exposure.

Moreover, the number or shape of nozzles is not specifically restricted, and it is acceptable, for example, to perform supply and recovery of liquid 7 using two pairs of nozzles in the length direction of end 32A. Also, in this case, it is also acceptable to arrange the discharge nozzles and inflow nozzles lined up vertically to be able to perform supply and recovery of liquid 7 from either the +X direction or the –X direction.

Also, when moving the wafer W in steps in the Y direction, as with the first embodiment, supply and recovery of liquid 7 is performed from the Y direction.

Figure 7 shows the positional relationship of end 32A of lens 32 of projection optical system PLA and the discharge nozzles and inflow nozzles for the Y direction, and in this Figure 7, when moving the wafer in steps in the non scan direction (–Y direction) that is orthogonal to the wafer scan direction, supply and recovery of liquid 7 is performed using discharge nozzle 27a and inflow nozzles 29a and 29b aligned in the Y direction, and when moving the wafer in steps in the +Y direction, supply and recovery of liquid 7 is performed using discharge nozzle 28a and inflow nozzles 30a and 30b aligned in the Y direction. Also, the supply volume Vi (m^3/s) and recovery volume Vo (m^3/s) of liquid 7 are determined using the formula below.

$$Vi = Vo = D_{SX} \cdot v \cdot d \quad (5)$$

Here, D_{SX} is the length (m) of end 32A of lens 32 in the Y direction. As with the first embodiment, by adjusting the supply volume of liquid 7 according to the velocity of the motion v of wafer W when moving in steps in the Y direction, it is possible to continuously fill the space between lens 32 and wafer W with liquid 7.

When moving wafer W as described above, by passing liquid in the direction according to the direction of motion, it is possible to continuously fill the space between wafer W and the end of the projection optical system Pl with liquid 7.

Moreover, the liquid used for liquid 7 for the embodiment noted above is not specifically restricted to purified water, and it is also possible to use an item (e.g. cedar oil, etc.) that has the highest refractive index possible while still having transmittance for the exposure light and that is stable relative to the projection optical system and the photoresist coated on the wafer surface.

Also, as liquid 7, it is also possible to use a liquid that is chemically stable, in other words, a fluorinated inert liquid that is safe and has high transmittance relative to exposure light. As this fluorinated inert liquid, it is possible to use Fluorinert (U.S. 3M Co. product name), for example. This fluorinated inert liquid is also excellent in terms of its cooling effect.

It is also possible to recycle recovered liquid 7 with each of the previously described embodiments, and in this case, it is preferable to provide a filter that removes impurities from recovered liquid 7 on the liquid recovery device or the recovery pipe, etc.

Furthermore, the scope of flow of liquid 7 only needs to be set to cover the entire area of the reticle pattern image projection area (exposure light irradiation area), and this can be any size, but it is preferable to have it be slightly larger than the exposure area as described with each of the embodiments noted above yet as small as possible for the purpose of controlling the flow velocity and flow rate. Also, it is difficult to recover all the supplied liquid with an inflow nozzle, so it is preferable to form a dividing wall that encloses the wafer, for example, so that liquid does not overflow from above the Z stage, and to further provide a pipe for recovering liquid from within this dividing wall.

Also, with each of the embodiments described above, liquid 7 was passed along the direction of motion of wafer W (XY stage 10), but it is not necessary to match the liquid 7 flow direction and this direction of the motion. Specifically, it is also acceptable to have the liquid 7 flow direction and the direction of the motion intersect, for example when wafer W is moving in the +X direction, liquid 7 can be passed in the direction where the velocity component of liquid 7 in the –X direction is either 0 or below a predetermined tolerance. By doing this, when a wafer is exposed using the step-and-repeat method or the step-and-scan method (both including the step-and-stitch method), even if the direction of motion changes frequently in a short time (for example a few hundred ms), it is possible to control the direction a fluid is passed to follow this, and to fill the space between the projection optical system and the wafer with the liquid. Also, in a step-and-scan method projection exposure apparatus, the motion of the XY stage is controlled so that when the wafer is moving between shot areas, the velocity components of both in the scan direction and non scan direction of the XY stage do not become zero, specifically, after scanning exposure within one shot area is completed and during deceleration of the XY stage (before the velocity component in the scan direction becomes zero), stepping (motion in the non scan direction) of the XY stage is started, and before this stepping ends (before the velocity component in the non scan direction becomes zero, and for example during deceleration of the XY stage), XY stage acceleration starts for scanning exposure of the next shot area. In this kind of case as well, the liquid flow direction is controlled according to the direction of the wafer motion, and it is possible to fill the space between the projection optical system and the wafer with a liquid.

Moreover, the application of the projection exposure apparatus of this example is not limited to a projection exposure apparatus for semiconductor manufacturing, and for example can be widely used for projection exposure apparatuses for liquid crystal that exposes a liquid crystal display device pattern on a square shaped glass plate or for a projection exposure apparatus for manufacturing thin film magnetic heads, for example.

Also, there are cases where reticles or masks used in exposure apparatuses for manufacturing devices that manufacture semiconductor devices, etc. are manufactured by exposure apparatuses that use far ultraviolet rays or vacuum ultraviolet rays, and the projection exposure apparatuses of each of the embodiments described above can also be suitably used for photolithography processes for manufacturing reticles and masks.

Furthermore, it is also acceptable to use a higher harmonic wave by amplifying a single wavelength laser of the infrared area or visible range oscillated from a fiber laser or a DFB laser as the illumination light for exposure using a fiber amplifier doped with erbium (Er), for example (or both erbium and ytterbium (Yb)), and by converting the wavelength to that of the ultraviolet light by using a non-linear optical crystal.

Also, projection optical system PL could be either a dioptric system or a cataoptric system or a catadioptric system. As a catadioptric system, as disclosed in U.S. Patent No. 5788229, for example, it is possible to use an optical system in which plurality of dioptric elements and two cataoptric elements (at least one being a concave mirror) are arranged on the optical axis extending in a straight line without any folding. In the exposure apparatus that has the catadioptric system disclosed in this U.S. patent, the optical element that is closest to the wafer, in other words that contacts the liquid, is a cataoptric element. Also, the disclosure of this U.S. patent is noted in part in this document by reference only as allowed by the domestic laws of predetermined countries or among selected countries predetermined or selected in this international application.

Also, by incorporating an illumination optics and projection optical system consisting of plurality of lenses in the main unit of the exposure apparatus and adjusting the optics, and also mounting a reticle stage and wafer stage comprising many mechanical parts in the main unit of the exposure apparatus and connecting wiring and pipes, and by providing the pipes for performing liquid supply and recovery (supply pipes, discharge nozzles, etc.), and by further making overall adjustments (electrical adjustments, motion

checks, etc.), it is possible to manufacture the projection exposure apparatus of this embodiment. It is also preferable to manufacture the projection exposure apparatus in a clean room where the temperature and degree of cleanliness, etc. are controlled.

Then, a semiconductor device is manufactured by going through a step of performing device function and performance design, a step of manufacturing a reticle based on that step, a step of producing a wafer from a silicon material, a step of exposing a wafer with a reticle pattern using a projection exposure apparatus of the embodiment described above, a step of assembling the device (including the dicing process, bonding process, and packaging process), and an inspection step, etc.

Also, the present invention is not limited to the embodiments noted above, and it is possible to use a variety of structures in a range that do not stray from the gist of the present invention. Furthermore, all the disclosed contents of Japanese Patent Application No. 10-79263 submitted on March 26, 1998 including the specification, claims, figures, and abstract are cited verbatim and incorporated here.

Industrial Uses

With the first and second projection exposure methods of the present invention, a liquid immersion method is used, so it is possible to expand the depth of focus of the mask pattern image by approximately a factor of n (n is the refractive index of the liquid used) of the depth of focus in air, and it is possible to do a stable transfer of a detailed pattern at high resolution. Therefore, it is possible to mass-produce high integration semiconductor devices, etc. at high yields. Also, when moving the substrate along a predetermined direction, because the liquid is passed along the direction of the motion of the substrate so as to fill the space between the end of the optical element on the substrate side of the projection optical system and the surface of the substrate, even when moving the substrate, the space between the end of the projection optical system and the surface of the substrate can be

filled with the liquid, and the liquid immersion method can be used. When particles have adhered to that substrate, it is possible to flush out the particles that have adhered on the substrate, so there is the advantage of being able to try to increase the final product yield.

Next, with the first and second projection exposure apparatuses of the present invention, it is possible to implement the first and second projection exposure methods of the present invention. Also, when adjusting the liquid supply volume and recovery volume (flow rate) according to the velocity of the motion of the substrate stage, even if the velocity of the motion of the stage changes, it is possible to keep the volume of the liquid that exists between the end of the projection optical system and the surface of the substrate constant.

Claims

1. A projection exposure method that irradiates exposure beams on a mask and transfers the pattern of said mask onto a substrate via a projection optical system, wherein

when said substrate is moved along a predetermined direction, a predetermined liquid is passed along the direction of the motion of said substrate so as to fill the space between the end of the optical element on said substrate side of said projection optical system and the surface of said substrate.

2. A projection exposure apparatus that irradiates exposure beams on a mask and transfers the pattern of said mask onto a substrate via a projection optical system,

comprising a substrate stage that moves while holding said substrate, a liquid supply device that supplies a predetermined liquid along a predetermined direction via pipes for supply so as to fill the space between the end of the optical element of said substrate side of said projection optical system and the surface of said substrate, and a liquid recovery device that recovers said liquid from the surface of said substrate via said supply pipes and pipes for discharge arranged so as to sandwich the irradiation area of said exposure beams in said predetermined direction, and wherein

when said substrate stage is driven to move said substrate along said predetermined direction, supply and recovery of said liquid is performed.

3. The projection exposure apparatus of claim 2 provided with a second pair of supply pipes and discharge pipes arranged at the location where said pair of supply pipes and discharge pipes would be if they were essentially rotated by 180 °.

4. The projection exposure apparatus of claim 2 or 3 wherein

said projection exposure apparatus is a scanning exposure type that performs exposure by moving the mask and substrate synchronously in relation to said projection optical system, and said predetermined direction is the scan direction of said substrate during scanning exposure.

5. The projection exposure apparatus of claim 2, 3 or 4 wherein

one pair of supply pipes and discharge pipes are arranged corresponding to said pair of supply pipes and discharge pipes in a direction orthogonal to said predetermined direction, or two pairs of supply pipes and discharge pipes are provided in reverse to each other.

6. The projection exposure apparatus of any of claims 2 through 5,

having a control system that adjusts the supply volume and recovery volume of said liquid according to the movement speed of said substrate stage.

7. The projection exposure apparatus of any of claims 2 through 6 wherein

said liquid supplied to the surface of said substrate is purified water adjusted to a predetermined temperature or is a fluorinated inert liquid.

8. A projection exposure apparatus manufacturing method wherein

an illumination optics that irradiates exposure beams on a mask, a projection optical system that transfers the pattern image of said mask onto a substrate, a substrate stage that holds said substrate and moves, a liquid supply device that supplies a predetermined liquid along a predetermined direction via supply pipes so as to fill the space

between the end of the optical element on said substrate side of said projection optical system and the surface of said substrate, and a liquid recovery device that recovers said liquid from the surface of said substrate via discharge pipes arranged together with said supply pipes so as to sandwich said exposure beam irradiation area in said predetermined direction are all assembled in a predetermined positional relationship.

9. A device manufacturing method using the projection exposure method of claim 1, including an exposure process by which the mask is irradiated by an exposure beam and said mask pattern is transferred onto a substrate via a projection optical system, and with said exposure process, when said substrate is moved along a predetermined direction, a predetermined liquid is passed along the direction of the motion of said substrate so as to fill the space between the end of the optical element on said substrate side of said projection optical system and the surface of said substrate.

10. A projection exposure method that irradiates a mask with an exposure beam and exposes a substrate with said exposure beam via a projection optical system, wherein

a liquid is passed so as to fill the space between said projection optical system and said substrate and the direction of the flow of said liquid is changed according to the direction of the motion of said substrate.

11. The projection exposure method of claim 10 wherein

when the supply speed of said liquid is divided into a first component in the direction of the motion of said substrate and a second component that is orthogonal to said direction of the motion, when said first component is in the reverse direction to the direction of the motion of said substrate, said liquid is passed in the manner that the first component is at a predetermined tolerance value or less.

12. The projection exposure method of claim 10 wherein

said liquid is passed in the same direction almost along the direction of the motion of said substrate.

13. The projection exposure method of claim 12 wherein

said substrate is exposed by the step-and-repeat method or the step-and-scan method, and said liquid flows almost along the stepping direction of said substrate.

14. The projection exposure method of claim 12 or 13 wherein

said mask and said substrate are respectively moved relative to said exposure beam, and while said substrate undergoes scanning exposure by said exposure beam, during said scanning exposure, said liquid flows almost along the scan direction of said substrate.

15. The projection exposure method of any of claims 10 through 14 wherein

the flow rate of said liquid is adjusted according to the speed of the motion of said substrate.

16. A device manufacturing method using the projection exposure method of any of claims 10 through 15 that includes a lithographic process that has a process of transferring a device pattern onto a substrate.

17. A projection exposure apparatus that irradiates a mask using an exposure beam and that transfers using said exposure beam onto a substrate via a projection optical system, and having

a liquid supply device that flows liquid so as to fill in the space between said projection optical system and said substrate, and that changes the direction of the flow of said liquid according to the direction of the motion of said substrate.

18. The projection exposure apparatus of claim 17 wherein

when the supply speed of said liquid is divided into a first component in the direction of the motion of said substrate and a second component orthogonal to said direction of the motion, said liquid supply device flows said liquid so that said first component becomes a predetermined tolerance value or less when said first component is in the reverse direction to the direction of the motion of said substrate.

19. The projection exposure apparatus of claim 18 wherein

said substrate is exposed by the step-and-repeat method or the step-and-scan method, and said liquid supply device flows said liquid almost along the stepping direction of said substrate.

20. The projection exposure apparatus of any of claims 17 through 19 further comprising

a stage system that moves said mask and said substrate respectively relative to said exposure beam, and said liquid supply device flows said liquid almost along the direction of the motion of said substrate during said substrate scanning exposure.

21. The projection exposure apparatus of any of claims 17 through 20 further comprising

a liquid recovery device that recovers liquid supplied to between said projection optical system and said substrate.

22. The projection exposure apparatus of claim 21 wherein

the supply port of said liquid supply device and the recovery port of said liquid recovery device are arranged so as to sandwich said exposure beam irradiation area.

Figures:

Fig. 5: Scan direction

Fig. 6: Scan direction, scan direction

Fig. 7: Scan direction